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THESIS

REAL TIME IMAGING OF INFRARED SCENE DATA
GENERATED BY THE NAVAL POSTGRADUATE SCHOOL
INFRARED SEARCH AND TARGET DESIGNATION
(NPS-IRSTD) SYSTEM

by

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A system to display images generated by the Naval Postgraduate School Infrared Search and Target Designation System (a modified AN/SAR-8 Advanced Development Model) in near real time was developed using a 33MHz NIC computer as the central controller. This computer was enhanced with a Data Translation DT2861 Frame Grabber for image processing and an interface board designed and constructed at NPS to provide synchronization between the IRSTD and Frame Grabber. Images are displayed in false color in a video raster format on a 512 by 480 pixel resolution monitor.

Using FORTRAN, programs have been written to acquire, unscramble, expand and display a 3° sector of data. The time line for acquisition, processing and display has been analyzed and repetition periods of less than four seconds for successive screen displays have been achieved. This represents a marked improvement over previous methods necessitating slower Direct Memory Access transfers of data into the Frame Grabber.

Recommendations are made for further improvements to enhance the speed and utility of images produced.

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by

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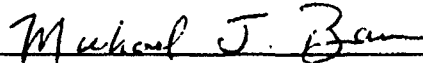B.S., United States Coast Guard Academy

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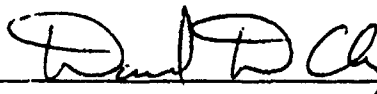from the

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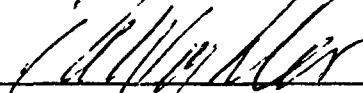September 1990

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ABSTRACT

A system to display images generated by the Naval Postgraduate School Infrared Search and Target Designation System (a modified AN/SAR-8 Advanced Development Model) in near real time was developed using a 33MHz NIC computer as the central controller. This computer was enhanced with a Data Translation DT2861 Frame Grabber for image processing and an interface board designed and constructed at NPS to provide synchronization between the IRSTD and Frame Grabber. Images are displayed in false color in a video raster format on a 512 by 480 pixel resolution monitor.

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ACKNOWLEDGEMENTS

I. INTRODUCTION

Infrared Search and Track (IRST) systems are designed to detect and track targets at maximum range and to declare targets with high reliability and a low false alarm rate. The usefulness and reliability of such systems is dependent largely upon their ability to discriminate unresolved targets from background clutter. Accumulated data is generally processed at a low rate due to hardwired background clutter rejection techniques. Typically, a system operator sees only processed alpha-numeric output representing target tracks at a near real time rate.

In many situations it would be beneficial for the operator to see the infrared scene being investigated, even though the sensor may not be optimized for this purpose. The real time or near real time display of background scenes as false color representations of temperature or radiance distributions requires the transfer of a large stream of data from the rotating scanner of the IRSTD to a computer station where it can be processed and displayed. Proper display of the background scene requires scan conversion from the parallel array imaging scanner to a raster display format of a color video monitor.

This thesis project is a follow-on to a project completed by Lt. Raymond Engel, USCG, in September 1989 [Ref. 1]. Engel developed a method which enabled tape-recorded infrared scene data generated by the Naval Postgraduate School Infrared Search and

Target Designation System (NPS-IRSTD) to be displayed in color-temperature representation on a video monitor. Once displayed on a video monitor, image enhancing techniques such as high or low-pass filtering could be employed to provide images useful in the detection of targets of military interest. While useful as a research and calibration tool, this method is very time consuming and unusable in an environment where information is needed real time or within a few seconds of real time (for example, in the detection of low flying antiship missiles).

This project continues Engel's work by pursuing a method in which the data generated by the NPS-IRSTD may be displayed very near real time, rather than by recording the data and then processing it upon playback at a slower speed. This task requires changing from lower speed computer-controlled data transfer (Direct Memory Access) to faster, direct digital input into a high speed image processing board through a newly designed interface board. Ultimately, scan conversion and display should occur within two seconds so that eventually, the same sector of data may be displayed within the two second rotation time of the IRSTD.

The three primary elements used in the pursuit of this objective were a 33MHz NIC IBM compatible personal computer, a Data Translation DT2861 Frame Grabber Board (hereafter referred to as "framegrabber") and an interface board designed at NPS specifically for this project. The framegrabber is a high speed image processing board allowing output to a dedicated video monitor.

The interface board was designed and constructed to synchronize the IRSTD and the framegrabber.

At the outset of this project the general concept of the procedures to produce real-time images was as follows:

- Read data into the framegrabber board via an external port.
- Write the data from the framegrabber into an array in computer memory.
- Process the data into a proper format for display using software (Fortran).
- Write the data from the array into the framegrabber.
- Display the image on a video monitor.

In order to produce real time images, it is necessary that the steps outlined above be accomplished in less than the two second rotation time of the IRSTD so that the framegrabber may be re-initialized to accept data by the time the IRSTD scanner has returned to the same sector. It was for this reason that such a high speed computer was selected for completion of this project.

In obtaining results, it was necessary to use tape recorded data played back at normal speeds due to a problem with the IRSTD which could not be corrected within the time-frame of this project. Nevertheless, results obtained from actual use of the IRSTD would be the same since transmission of the data to the framegrabber board exactly matches that from the IRSTD and the data on tape is actual data taken from the IRSTD.

II. THE NPS-IRSTD

A. BACKGROUND OF THE NPS-IRSTD

This section will provide the reader with broad background of the Naval Postgraduate School Infrared Search and Target Designation System. This information was obtained from Lt. Engel's thesis [Ref. 1] and through general conversation with Professor Cooper and Research Associate William Lentz. Further details and reference may be found in References 2, 3 and 4.

The NPS-IRSTD is a passive, scanning infrared detection system. Originally an AN/SAR-8 IRSTD Advanced Development Model (ADM), the first prototype testing of this system took place in 1969. It was designed to be a shipboard system capable of providing surface ships with a method of detecting and tracking air targets. It operates on the principle that all objects operating above absolute zero (0 K), emit radiation. In particular, missiles, aircraft and surface ships emit radiation in the infrared. Therefore, the AN/SAR-8 is an excellent means of detecting, evaluating and tracking such targets of interest without using a source of illumination.

Stemming from a United States-Canadian Memorandum of Understanding signed in 1976, the system underwent several years of extensive testing and evaluation, both afloat and ashore, including at-sea trials by the Canadian Navy. In January, 1985 the ADM was

obtained by the Naval Academic Center for Infrared Technology (NACIT) at the Naval Postgraduate School (NPS). Extensive alterations and repairs after arrival at NPS have modified the system so that is no longer has all the characteristics of the ADM and thus, the system is now referred to as the NPS-IRSTD (or IRSTD, as will be the case in this thesis).

B. COMPONENTS OF THE NPS-IRSTD

The following sections will summarize the major components of the IRSTD, including their location and function within the overall system. In general, the IRSTD consists of four major components: the Scanner Assembly, a Buffer and Power Unit, a Data Conditioner Unit, and a computer to manipulate and display the data. Although it is part of the computer system, an entire subsection will be devoted to the Data Translation DT2861 Frame Grabber since it plays an especially significant role in processing raw scene data.

1. Scanner Assembly

The scanner assembly of the IRSTD, located on the eighth floor (roof) of Spanagel Hall on NPS grounds, scans 360° horizontally, from 1/2° below the horizon to 10° above the horizon. Figure 1 shows the IRSTD scanner and buffer/power unit atop Spanagel Hall. The scanner assembly houses, among other hardware:

- Schmidt F/1 catadioptric telescope.
- Two vertical 90 detector arrays which operate in the 3 to 5μm infrared range.
- Liquid nitrogen cooling system.

SCHEMATIC OF THE NPS-IRSTD OPTICAL SYSTEM

SPHERICAL MIRROR

INFRARED WINDOW

LIQUID NITROGEN

FOAM INSULATED CYLINDER

FILTER AND DETECTOR ASSEMBLY

SCHMIDT
F/1
10 INCH DIAM APERTURE
ADJUSTABLE FOCUS

ASPHERIC CORRECTOR

TARGET ENERGY
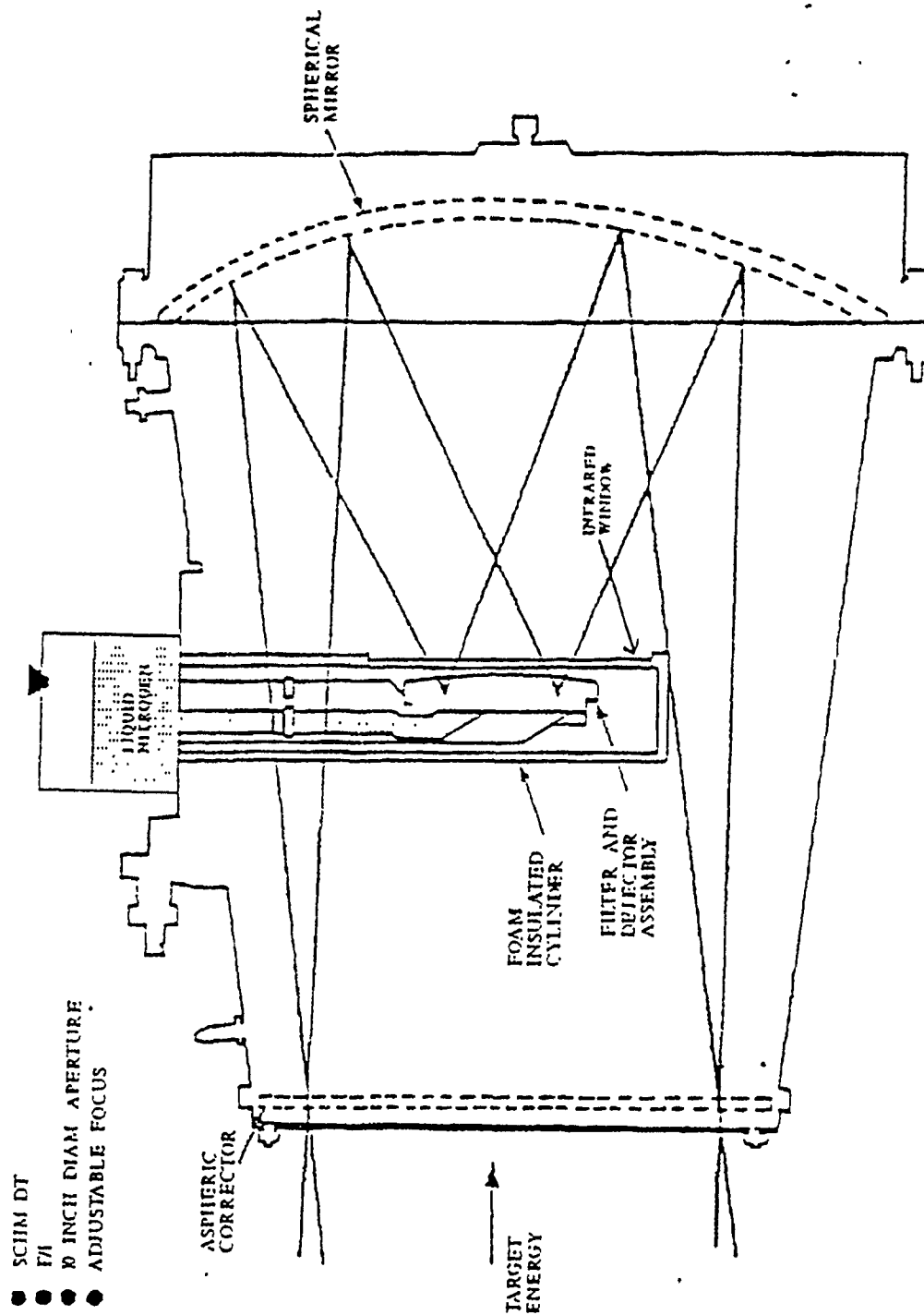
Figure 1   NPS-IRSTD Telescope and Detector Assembly

• Detector signal breakout and multiplexing hardware.

Slip ring assembly to transmit data from the rotating head to the fixed base of the scanner assembly.

a. Schmidt F/1 Telescope

The Schmidt F/1 telescope assembly is shown in figure 2. Infrared radiation enters the telescope through a 10" germanium corrector plate and is focused onto the detectors by a 16" diameter spherical mirror at the back of the telescope. The detectors are housed in a liquid nitrogen cooling assembly, but receive radiation through a germanium window mounted in the cooling assembly.

b. Detectors

The NPS-IRSTD detectors are Indium Antimonide (InSb) photodiodes, which convert radiation to an electrical signal via the photovoltaic effect. InSb has an energy band gap which is similar to the energy of radiation in the 3 to $5\mu m$ range. Thus, when infrared radiation in this waveband strikes the detectors, an electrical signal is generated. Since the energy of a photon is governed by the relationship $E = hc/\lambda$, the detector material is a very important feature in the detection of a particular type of radiation. In addition, since the detectors are semiconductors, they are quantum detectors, whose electrical output is dependent upon the number of photons detected.

The detectors are arranged in two linear, vertical arrays. The arrays contain 90 detectors and are spaced ½° apart. Designed for long range target detection rather than imaging, the detectors subtend an instantaneous field of view of 2.0

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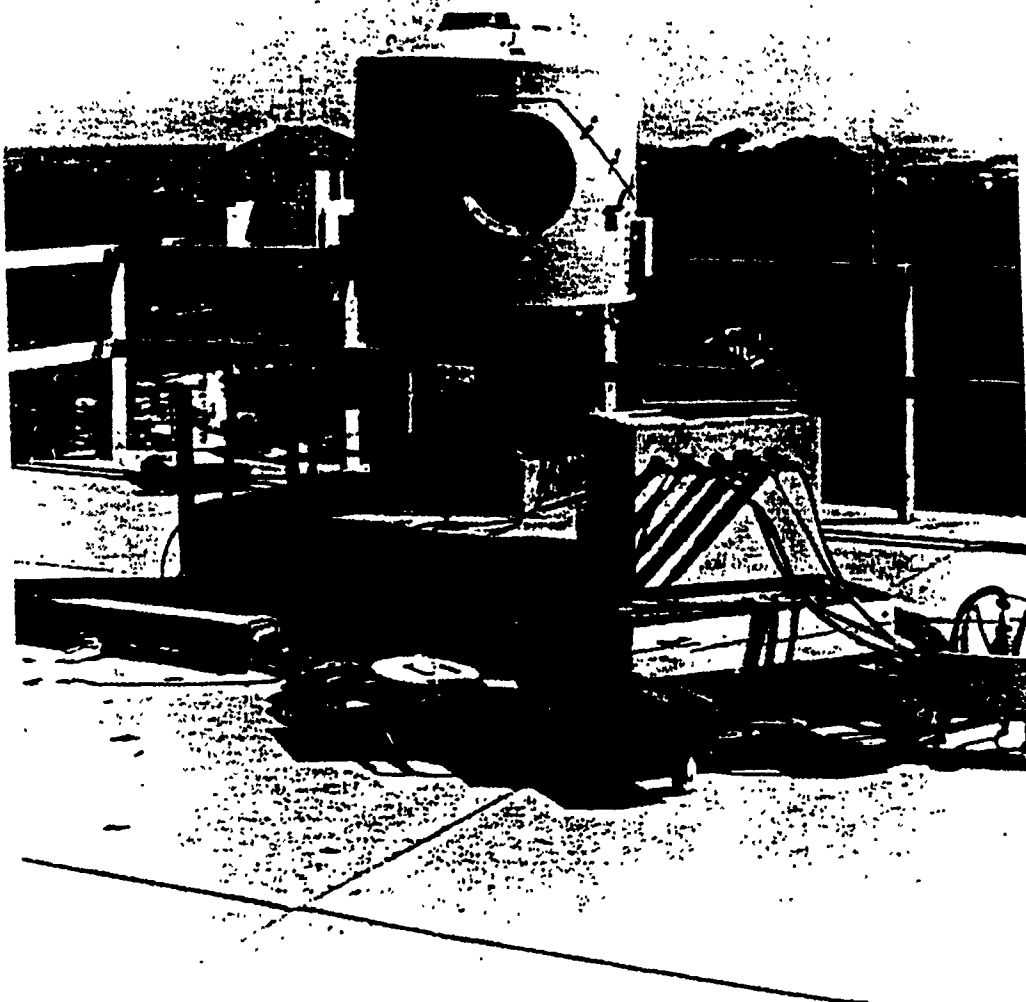
Figure 2 Photograph of NPS-IRSTD Scanner and Buffer and Power Unit

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vertically by 0.3 milliradians horizontally. Each detector is digitized at 30kHz, or 60,000 samples per revolution (one revolution takes two seconds). The horizontal sampling rate of each array is .1047 milliradians per digitization.[Ref. 5] On a video monitor, with each byte of data representing one pixel on a 512 by 512 screen, approximately 3° of horizon can be shown.

c. Detector Cooling System

Because InSb has such a small band gap, the voltage that it generates is subject to thermal noise fluctuations. That is, electrons are easily thermally excited across the band gap, thereby creating thermal noise. This thermal noise voltage may mask or distort the voltage produced by the detection of photons. Therefore, it is essential that the detectors be kept cool to eliminate this source of noise. Cooling is accomplished by refrigerating the detectors with liquid nitrogen. A simplified cross-sectional model of the cooling system is shown in Figure 3. As depicted in the figure, liquid nitrogen fills the detector support stalk and refrigerates the detectors to 85K. Heating elements bordering the germanium window prevent the accumulation of condensation on the window surface which would block infrared radiation. Lastly, the cooling element is wrapped in a jacket of insulating foam which prevents thermal transfer between the stalk and its surroundings.

d. Breakout Box and Multiplexing Hardware

Signals produced by the ninety detector operational or "lead" array are fed into a ninety connection point breakout box,
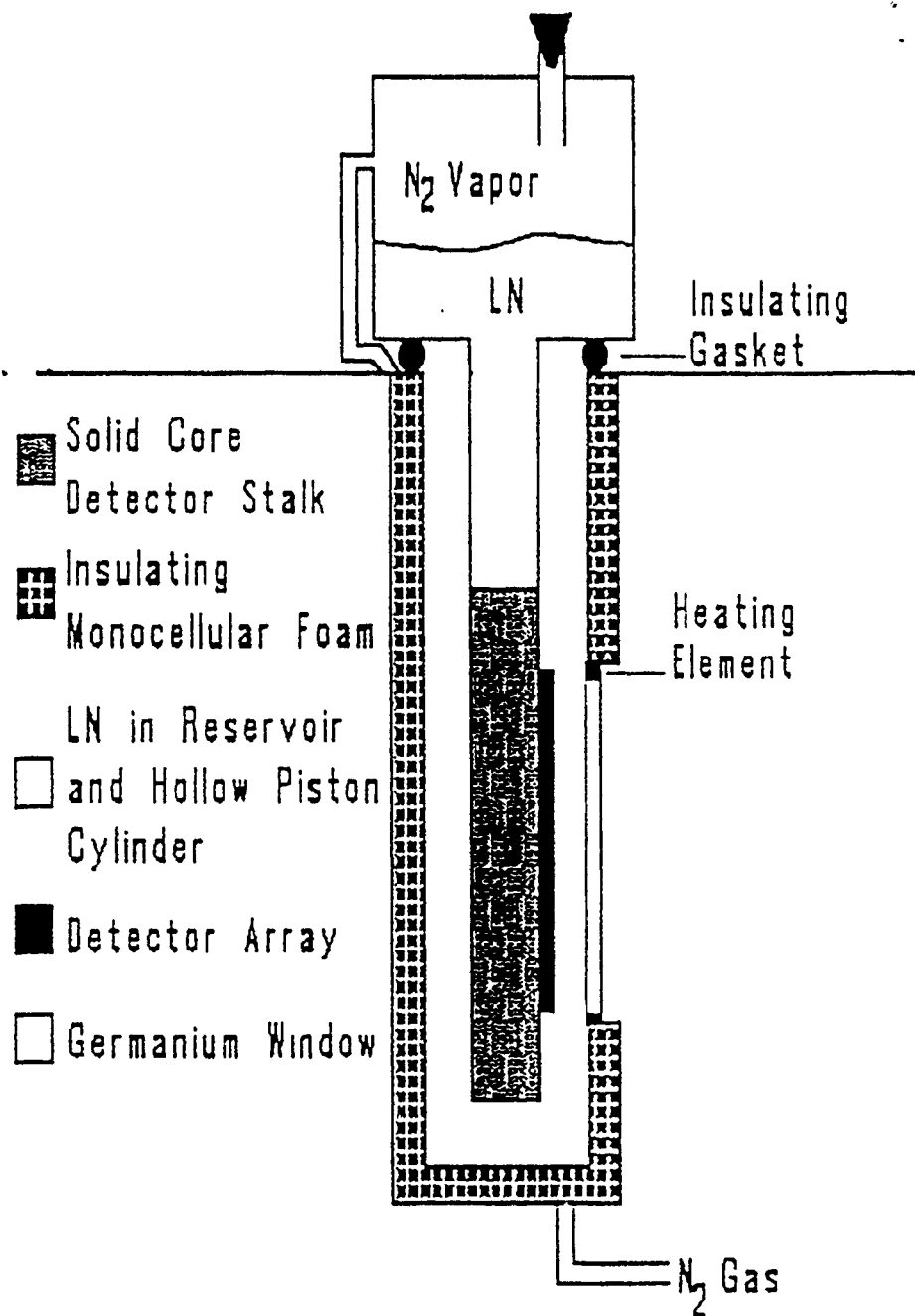
Figure 3 Simplified Diagram of the NPS-IRSTD's Detector Cooling Apparatus [Ref. 3]

one detector channel per connection point. This break-out box allows direct access to data for processing and manipulation. In the breakout box the ninety channels are multiplexed into six lines, using one multiplexer for every fifteen detector channels. This multiplexing reduces the number of cables running to Room 703 of Spanagel Hall, the location of more electronic processing hardware. Each multiplexer selects each of its fifteen channels for output at one time; therefore, at any given time, the six multiplexer outputs are for detectors spaced fourteen apart. The multiplexing is shown in Figure 4.

e. Slip-ring Assembly

The slip ring assembly is the hardware that transmits the electrical signals from the rotating head to the fixed base of the IRSTD. There is one slip ring for every multiplexer channel and several others for timing and synchronization. An individual slip ring unit consists of a copper strip mounted on the bottom of the rotating head. Contact brushes are attached to the fixed base and are in constant contact with the rotating copper strip.

2. Buffer and Power Unit

After the detection of infrared radiation by the scanner assembly, the data must transmitted approximately 150' via cable to room 703 for signal processing. For this purpose, it is necessary to amplify and to alter the signals to match the required characteristics at each end of the transmission cable. The Buffer and Power Unit perform these functions. They are shown in Figure 1 to the right of the scanner assembly.

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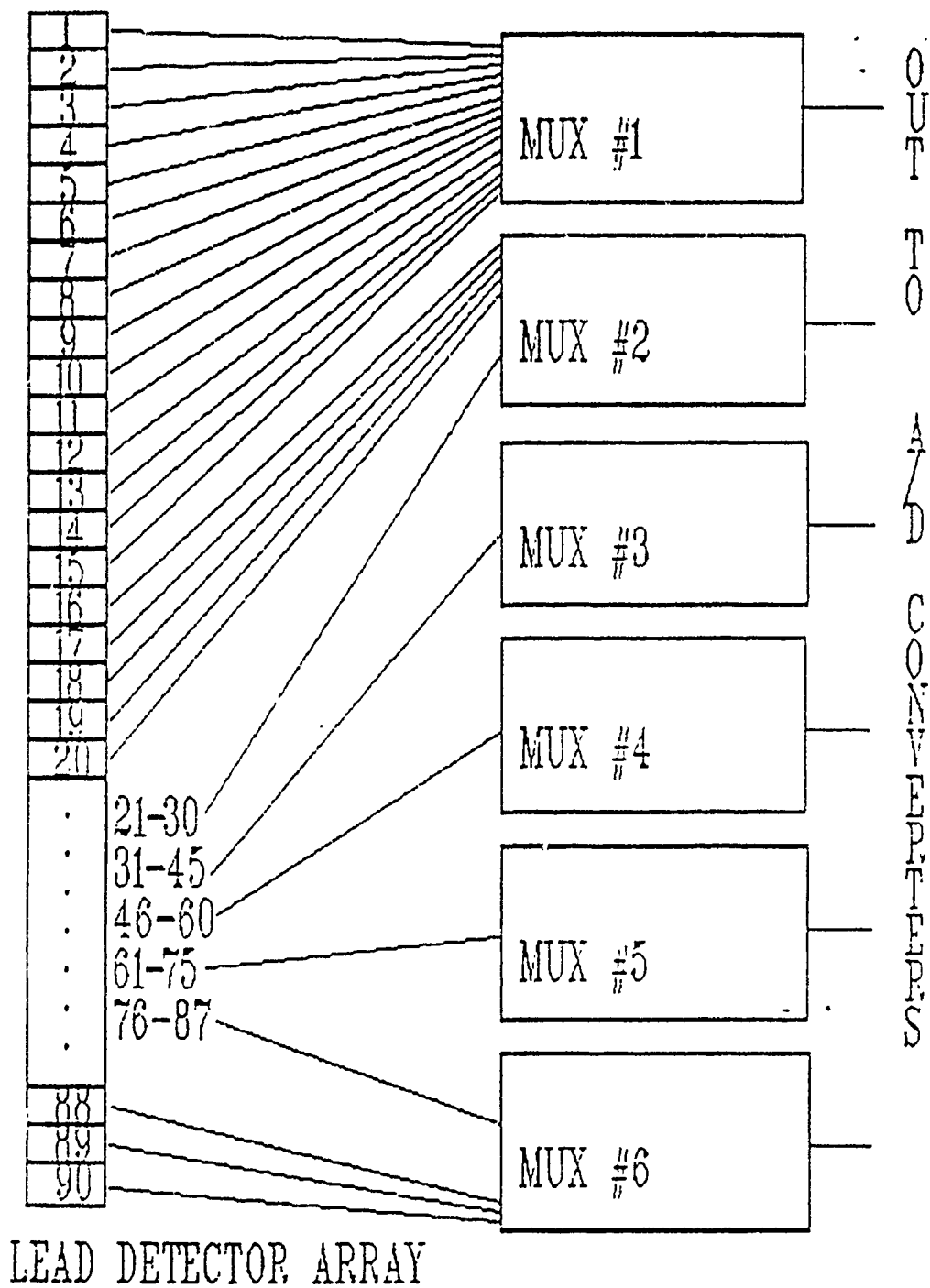
Figure 4 Analog-to-Digital Conversion and Multiplexing
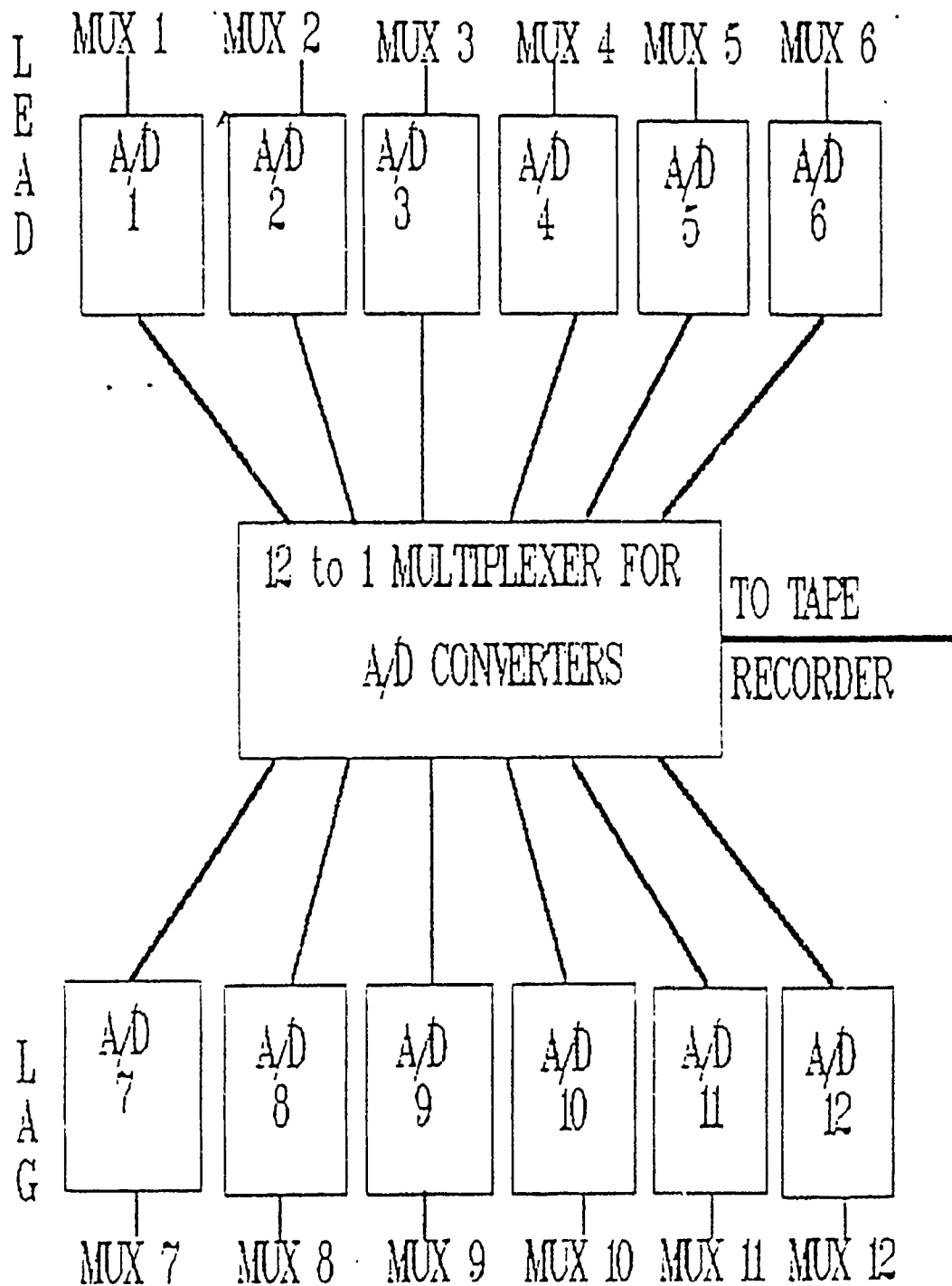
Figure 5 Multiplexing Arrangement for Lead Detector Array

3. Data Conditioner Unit

The Data Conditioner Unit, located in Room 703 of Spanagel Hall is a solid state processing unit that prepares the data for transmission to Room 212 of Spanagel Hall, where the data is processed and displayed on a video monitor. Figure 5 illustrates the multiplexing of the data performed by the Data Conditioner Unit. As shown in the figure, the data coming from the twelve multiplexers (six multiplexers per array) is digitized by the twelve analog-to-digital converters. This data is then further multiplexed by a twelve bit multiplexer prior to transmission to room 210. This multiplexing causes one of the major problems addressed in this thesis and will be expounded upon in greater detail in the next chapter.

4. NIC Computer System

As stated in the Introduction, the data produced by the IRSTD scanner must be processed and displayed every two seconds. Accordingly, the decision was made to upgrade the computer system from a 20 MHz Everex Step 20 to a 33 MHz NIC with an Intel 80386 microprocessor. The 33MHz machine would enable data to be processed almost 1.5 times as fast as the Everex Step 20. The 33 MHz NIC contains 640K bytes of memory and an additional 7168K bytes of extended memory. Other important components of the computer system include:

- Two hard drives (59 and 76 Megabytes for storage of applicable software and Fortran programs.

- Data Translation DT2861-60Hz Arithmetic Frame Grabber Board - an image processing board containing sixteen frame storage

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buffers. It is used to process images for display in false color and to perform various operations on images such as convolution, filtering, or even logical operations (AND, OR, NOR, etc.) between different buffers. [Ref. 6]

- Digital Interface Board - Designed and constructed at NPS as a major part of this project, this board is the interface between the source of data (tape recorder or IRSTD) and the framegrabber board.

- 40 Megabyte Tape Backup Drive - used to backup software in the development of the project. An essential element in the event of accidental erasure of the software on the hard disks.

- Color monitor for scene display with 800 column by 600 row maximum resolution.

5. Data Translation DT2861 Frame Grabber

The Data Translation DT2861 Frame Grabber is a high speed image processing board. It contains sixteen on board frame storage buffers, 256 KB each, for images 512 pixel rows high and 512 pixel columns wide. Although principally designed to allow the user to manipulate images after digitizing standard analog video signals, the board also accepts previously digitized data through an external port. Supplementing the framegrabber is DT-IRIS, an image processing software subroutine library. The framegrabber and DT-IRIS allow the user to perform a variety of functions, some of which are listed below:

- Acquisition and display of images.

- Manipulation of data through windowing and writing to and from arrays.

- Arithmetic operations such as addition and subtraction with other frame buffers.

- Logical operations (AND, OR, XOR) between two frame buffers.

- Convolutions and filtering.

- Zooming, panning, and scrolling to areas of interest. [Ref. 7]

In addition, the framegrabber allows the display of data using "false color." Each pixel displayed on the video monitor has a color or gray level depending upon the value of its byte in memory. Values range from 0 to 255 (eight bits in binary coded decimal) in each of three red, green, or blue assignable look-up tables. False coloring capabilities have been very useful in image enhancement and target discrimination [Ref. 1].

Having reviewed the background and major components of the IRSTD, this thesis will now proceed to explain the problems of displaying real-time data and the methods by which they were solved.

III. EXPERIMENTAL/ENGINEERING PROCEDURES

This chapter will explain in detail the software and hardware engineering involved in obtaining a real-time display of IRSTD data. The first section will describe the process by which data is gathered and processed by the IRSTD and then acquired by the DT2861 Frame Grabber Board. It will be shown explicitly how this data is loaded into the frame storage buffer of the framegrabber in an improper format. The next section will explain how this data is manipulated with Fortran and placed in a proper format for display on a video monitor. Lastly, the method in which the computer was interfaced to the tape recorder will be explained. The reader is reminded that tape recorded data was used instead of actual IRSTD data because of a current problem with the IRSTD. Nevertheless, data is transmitted to the computer from the tape recorder in exactly the same format as from the IRSTD, so that all problems that might be encountered with obtaining actual IRSTD data would be encountered with obtaining tape recorded data.

A. DATA ACQUISITION AND PROCESSING

As stated in Chapter II, the IRSTD has two side-by-side, vertical ninety-detector arrays which gather a particular frequency band of infrared scene data. The data gathered by an individual detector is digitized into eight bit bytes at a digitization rate of 30kHz. As the IRSTD scans the horizon, the detectors continue

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to gather scene data. Each byte of data generated by the IRSTD corresponds to one pixel of information on a standard 512 X 512 video monitor and, ideally, the data gathered by each array in one period of the 30kHz clock would correspond to one column of data, 90 pixels high on a video monitor. Furthermore, in the ideal situation, as the IRSTD scans across the horizon, the next set of data from an array would be displayed one pixel column to the right of the previous pixel column, with this same sequence continuing until a scene 512 pixels wide would be displayed for the user. Unfortunately, as a result of the multiplexing of the data into a single parallel transmission line and the method by which the framegrabber accepts data from its external port, the ideal situation does not occur. Both of these issues will be discussed in the following subsections.

1. Signal Multiplexing

Transmitting IRSTD generated data down five levels from room 703 to room 210 of Spanagel Hall makes necessary the multiplexing of the data from the two ninety-detector arrays into an eight bit parallel line of data. The data from the two ninety-detector arrays is multiplexed into twelve analog signal lines (six per array) after which the signal is converted from analog to digital. It is important to note the order in which the bytes of data are transmitted upon being multiplexed. Referring to Figure 4, and keeping in mind that there is a "lag" array with detectors numbered 91 through 180, when the input address lines of the twelve 15-to-1 multiplexers are set at zero, the multiplexer outputs are

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from detectors 1, 16, 31, 46, 61, 76, 91, 106, 121, 136 ,151 , and 166. These twelve lines are subsequently multiplexed by a 12-to-1 multiplexer (see Figure 5) and what results on the eight bit parallel transmission line is data from the detectors in the order listed above. Next, the input address lines of the 15-to-1 multiplexers change to one, and the output changes to data from detectors 2, 17, 32, 47, 62, 77, 92, 107, 122, 137, 152, and 167. This sequence continues as the input address lines of the 15-to-1 multiplexers cycle through fourteen and all 180 detector data values have been digitized and transmitted on the eight bit parallel transmission line. The final result is the following sequence of data being transmitted:

- 1,16,31,46,61,76,91,106,121,136,151,166,2,17,32,47,62,77,92,
  107,122,137,152,167,3,...,15,30,45,60,75,90,105,120,135,150,
  165,180.

2. Data Acquisition by Framegrabber Board

The previous subsection described the order in which bytes of data are transmitted from the IRSTD to the NIC personal computer containing the DT2681 Framegrabber Board. This subsection will describe how the framegrabber board accepts this data.

Data manipulation by the DT2861 Framegrabber Board is accomplished by the use of DT-IRIS, an image processing software subroutine library which is controlled in this case by the Fortran programming language [Ref. 7]. Data from the IRSTD (tape recorder) is transferred to the framegrabber board via an external data port, a 26-pin male right-angle ribbon cable connector. The DT-IRIS

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subroutine, "ISRDEP" (READ FROM EXTERNAL PORT) takes data from this external port and places it in a selected input frame buffer. A frame buffer is 512 lines (rows) high and 512 pixels (columns) wide, and thus stores 262,144 bytes of data. The data is loaded in the frame buffer pixel-by-pixel, starting at line #1, column #1, proceeding across through column #512, shifting down one row and returning to column #1 (like a carriage return), proceeding in this manner until all 512 rows of data have been loaded into the frame buffer. Recalling the sequence in which data is transmitted from the IRSTD to the framegrabber, it is apparent that the data is stored in the framegrabber in the wrong sequence. In order to have the desired scene displayed on the monitor, it is necessary that the data be stored in a position in the frame buffer which corresponds to the detector the data came from and its position in the IRSTD scan. Furthermore, although the two detector arrays may operate in different infrared bands, they cover the same vertical range offset by a time delay. Therefore, only every other array should be displayed. In carrying out this project it was decided that the scan conversion software should operate on the operational lead array. Thus, in an ideal situation, scene data taken by the lead array at the start of an IRSTD scan would occupy column #1, lines #1 through #90 in the frame buffer. As the IRSTD scans to the right, data would fill each successive column corresponding to data only from the lead array. However, due to the multiplexing explained earlier and the method by which the framegrabber accepts and stores data, the bytes from both arrays at the start of a scan

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are stored, being placed in row 1, columns 1 through 180 in the order 1, 16, 31, 46, 61, 76, 91, 106, 121, 136, 151 ,166, 2, 17, 32, 47,..., 15, 30, 45, 60, 75, 90, 105, 120, 135, 150, 165, 180. As the IRSTD scans, the next 180 detector digitizations are stored in row 1, columns 181 through 360. This sequence continues until a frame of data is loaded into the framegrabber board.

B. SCAN CONVERSION

The next step in obtaining a real time display is to manipulate the data in the framegrabber board such that it is in the proper sequence in a frame storage buffer and then use a DT-IRIS subroutine to display the frame buffer. The method by which data is prepared for display is described in subsequent subsections. Also, in order to provide flexibility for future users, separate programs were written and compiled to perform the functions of acquiring the data and converting it to a proper format. These two programs are entitled LOAD and UNSCRAMB. Since UNSCRAMB should be run directly after LOAD, an executable batch file entitled REALTIME, was created to run them consecutively. A listing of the code for these programs is contained in Appendix A. In addition, basic instructions for compiling, linking and running these programs are contained in Appendix B.

1. Data Processing

In general, there are three major problems with the format of the data in a frame buffer upon receipt from the IRSTD:

• As the IRSTD scans, each 180 byte set is loaded into the framegrabber board horizontally and side-by-side, rather than in successive 90-byte-high columns. Furthermore, since the frame buffer is 512 pixels wide, some portion of the set of data being loaded into the right-most side of the frame buffer is forced into left side of the next line down.

• The data within each set of 180 bytes is "scrambled" in the sequence described in the previous section.

• Data in the frame buffer is from both arrays. On y data from the lead array is desired so that the display will contain information from only one optical band.

These problems are solved through the use of DT-IRIS subroutines which write the contents of a frame buffer to an array in computer memory. Once the data is in an array, it can be manipulated with Fortran, placed in the correct format, and reassigned to another frame storage buffer.

The first step in the conversion process is completed by unscrambling the detector elements within each 180-detector set. This is accomplished by writing the first 23040 bytes in the frame storage buffer into an array and then using another array to map the bytes into their proper position. Once in the proper position in an array the data can then be sent back to the framegrabber and placed in a second frame store buffer. The reason an array size of 23040 was chosen for data manipulation is that 23040 is the largest increment of 64 columns of data (128 columns including lead and lag array) within the DT-IRIS transfer limit of 32767 bytes [Ref. 7]. If the above process of transferring data to an array, unscrambling it, and sending to it a proper position in a frame storage buffer is repeated eight times, the result will be that the frame store

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buffer contains 1024 (8 X 128 = 1024) "columns" of data (512 columns per detector array) laid horizontally.

The next logical step is to take the data from each detector array and place it vertically in a frame storage buffer. This is accomplished by writing the horizontally-laid array data into a one-dimensional array and transferring it into a two-dimensional array in computer memory. The use of a two-dimensional array allows the placement of the data into a column format because data from the one dimensional array can simply be fed into the two-dimensional array column by column. Also, if only the data corresponding to the lead array is operated on, data from the lag array is filtered out, thereby solving the problem of having the lag array display the same scene as the lead array but delayed in time. Failure to filter out the lag array would result in a distorted image. At this point, the data is in a two-dimensional array in computer memory. It would seem that the data would simply have to be written to a frame storage buffer. It was here that a problem was encountered with the DT-IRIS subroutine ISPUTR which transfers data from an array in computer memory to a frame storage buffer. This subroutine would not transfer data from a two dimensional array into a buffer in the same format that the data was in the array. Attempts to do so resulted in scrambled images. This problem was solved by rewriting the data in the two-dimensional array into a one dimensional array without remapping any data points. Now when data was transferred into the frame

storage buffer and displayed the image was completely unscrambled and in a 90 row high by 512 column wide format.

Lastly, to aid the user in evaluation of data, it was decided that the ninety line image would be expanded into 450 lines to approximate a television display frame. This entailed taking each line in the frame storage buffer containing the ninety line image and mapping it into five lines of another frame storage buffer. Now the data was in its final format for display on the video monitor. Display of the data is accomplished by the DT-IRIS subroutine ISOTFR (SELECT OUTPUT FRAME). A chart of the complete scan conversion process is shown in figure 6.

C. HARDWARE ENGINEERING

At this juncture, it is clear that once data is inside the DT2861 Frame Grabber, it can be processed into a correct format for display. The remaining problem involves getting it into the framegrabber. As stated previously, the DT-IRIS subroutine ISRDEP initializes the framegrabber to accept a frame of data. At the instant the framegrabber is initialized, two problems must be solved:

- The framegrabber and IRSTD or tape recorder must "handshake." The framegrabber accepting data and the IRSTD or tape recorder transmitting data are two systems which operate independently. Such systems are termed "asynchronous" and require an interface technique called "handshaking" which is, very basically, a mutual agreement to synchronize.

- Data must be read from the first detector in each 180 detector set. If this is not accomplished, data will begin to load into the framegrabber from any of the detectors at random and ultimately will be scrambled upon being displayed.

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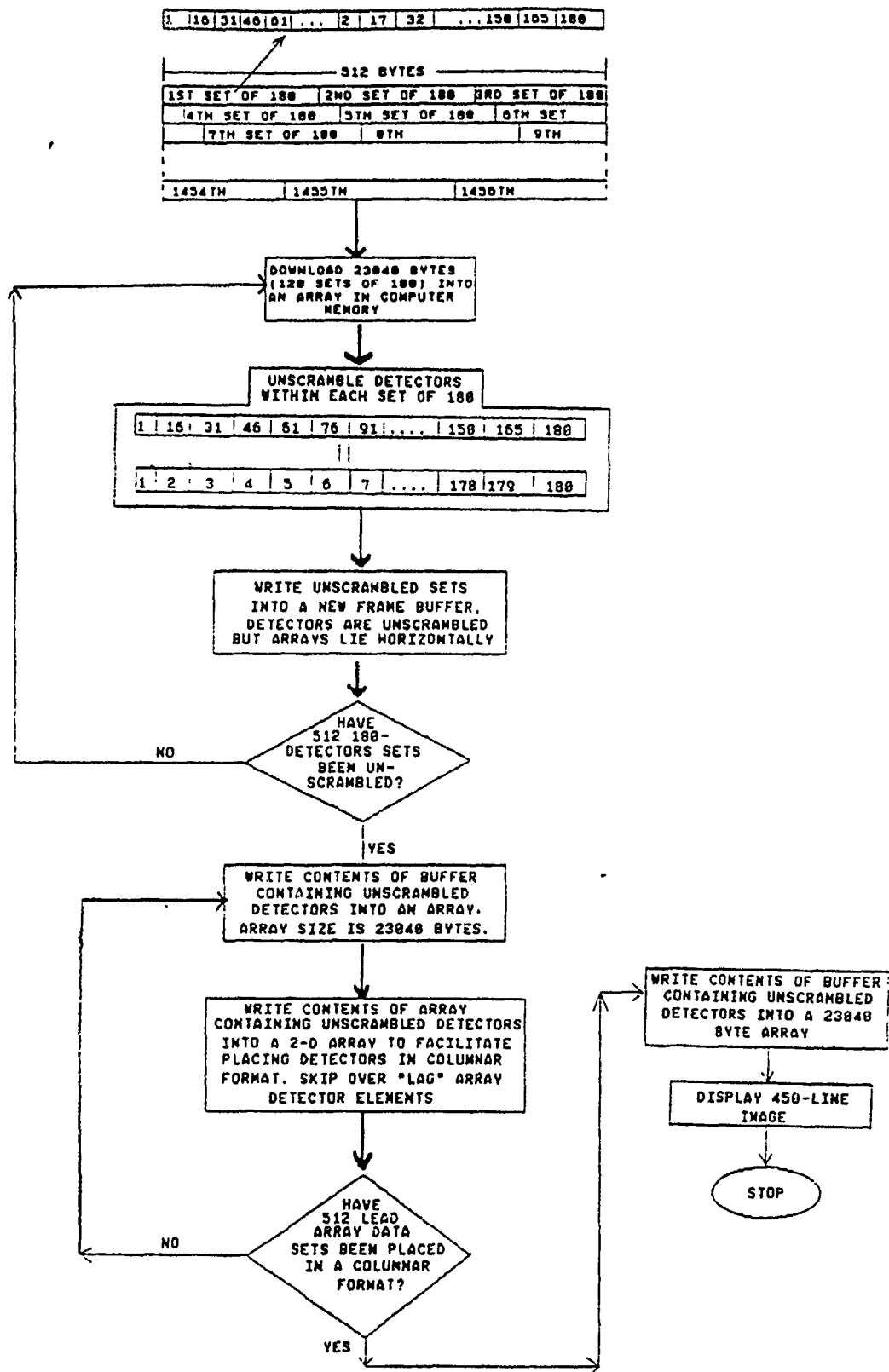
Figure 6 Scan Conversion Process

This section will explain how these two problems were solved with hardware, specifically an interface board designed at NPS by Research Associate William J. Lentz and constructed in cooperation with the author. This interface board is an internal card mounted inside the NIC computer with one external side to plug in the data cable from the IRSTD or tape recorder. Figures 7 and 8 are a schematic and input/output pin assignments, respectively, of this board.

The interface board carries two data paths that input to the framegrabber. The first of these constitutes a test data source using an on-board counter which continuously produces the binary numbers 0 through 255 in eight bit bytes (two 74LS193 chips in Figure 7) and an oscillator used as a clock (74LS13 strapped with resistor R1). The clock is synchronous with the byte production of the counter, simulating the synchronous clock signal produced by the IRSTD. The counter/clock circuit was used as a test circuit for the software, the handshaking circuitry and the framegrabber. Successful loading of test data and output to the video monitor results in a vertical bar pattern on the video monitor.

The second data path to the framegrabber is used for actual data input. This path is shown in Figure 7 as beginning with data bits one through eight as inputs to a 74LS373 octal latch. Either data path may be selected with a switch located on the external side of the interface board. The "down" position selects the internal counter as the data source and the "up" position selects

the tape recorder or IRSTD. In addition, the data path not in use is disabled by the external switch, preventing noise from the unused circuitry from interfering with the desired data.

1. Handshaking

Handshaking is necessary to synchronize two independent systems. It is a technique whereby some action taken by one party (framegrabber) is responded to by another party (IRSTD or tape recorder). The response of the second party indicates to the first party that the first party may again take action [Ref. 8]. The handshaking between the framegrabber and the IRSTD is accomplished by a flip-flop and two inverters on the interface board.

The input portion of the DT2861 Frame Grabber's external port is a 26-pin male right-angle ribbon cable connector. Eight of the twenty-six pins are for data bits, five are for digital grounds, nine are not used, and the other three are labeled "BUSY OUT", "REQUEST OUT", and "REPLY LOW" [Ref. 6]. The last three of the aforementioned pins are used for handshaking. The following sequence of events constitutes the handshaking protocol of the DT2861 as controlled by the interface board:

- BUSY OUT is driven low and must remain low any time data is being transferred to or from the framegrabber. BUSY OUT is driven low by the DT-IRIS command ISRDEP (Read From External Port).

- REQUEST LOW is driven low by the framegrabber. This event initiates the transfer of one byte of information by indicating that the framegrabber is ready to receive information. When this occurs the interface board must send data to the framegrabber board.

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Figure 7 Schematic of Interface Board

Figure 8 Input/Output Pin Assignments

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- The positive edge of the next clock pulse (synchronous with the data) causes the flip-flop to change states, driving REPLY LOW from high to low. When this occurs, the framegrabber latches the input data from the external port.

- The framegrabber drives REQUEST LOW from low to high. This event indicates that the framegrabber has received and latched a byte of information. [Ref. 6]

As shown in Figure 7, REQUEST LOW is inverted (by a 74LS14 inverter) so that the flip-flop will be forced into a "Q-high" state when REQUEST LOW is high. This overrides all clock inputs, and restricts the flip-flop from changing states to times when REQUEST LOW is low. The sequence listed above continues until 262,144 bytes have been loaded into the framegrabber, corresponding to a 512 X 512 image.

2. Synchronization With 1st Detector in a Set of 180

The framegrabber must begin reading data at the first detector in a set of 180. Not doing so would result in data placement in a frame store buffer in an arbitrary manner, making it impractical, if not impossible, to unscramble. For synchronization, the IRSTD generates a positive pulse at the beginning of each 180 detector scan. These pulses are carried on a separate line from the IRSTD and are also recorded on tape along with IRSTD data. Referring again to Figure 7, a synchronizing flip-flop is held in a "clear" state by the BUSY OUT signal until a frame of data is requested. When the BUSY OUT signal is driven low by the ISRDEP subroutine, the synchronizing flip-flop is allowed to change state on the next synchronizing pulse from the IRSTD. The output of the flip-flop then allows external clock

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pulses to pass into the handshaking circuitry until the BUSY OUT signal returns to a high state - that is, when a frame of data has been accepted.

IV. RESULTS

A. DATA TRANSFER

The attempt to transfer data from the tape recorder to the DT2861 Frame Grabber was completely successful - the interface board worked exactly as designed. Of course, there were very high expectations that the interface board **would** work with tape recorded data because it had already proven to be successful at transferring data generated by the test oscillator.

Testing the board was very easy because it only involved writing, compiling and running a Fortran program which would initialize the framegrabber, start the handshaking, and then have the framegrabber display the data on a video monitor. Using the test oscillator and counter to produce bytes of data with values from 0 through 255 resulted in vertical bands 256 pixels wide which were black at the left band edge, white at the right edge and an appropriate shade of gray in between, corresponding to the increasing pixel values from 0 (black) through 255 (white). The most encouraging part of this result, though, was that the board successfully transferred data to the framegrabber at 5.4 MHz, the digitization rate of the IRSTD. This result ultimately means that when the IRSTD is again operational, there is a high probability that real time transfer of data into the framegrabber board will be successful. The ability to present an image on successive

rotations will then depend on processing time and not on acquisition time.

After successful transfer of data using the test oscillator and counter, it remained to see if the interface board would transfer tape recorded data to the framegrabber. The switch on the interface board was toggled to disable the test oscillator and change the data path to the one which would transfer external data. The tape recorder was initially turned on at a slow speed for testing purposes. The test program was run, and a screen of scrambled data appeared on the video monitor. The speed of the tape recorder was incre·sed in increments and the interface board was tested at each speed. Data was successfully transferred and displayed each time, including at the tape recorder's maximum speed of 120 inches per second which corresponds to a playback digitization rate of 4.32 MHz. Unfortunately, because of the limitations of the tape recorder, it was not possible to test a digitization rate of 5.4 MHz. Nevertheless, successful data transfer from the IRSTD at this speed is highly probable because the board worked perfectly with a test circuit that simulates IRSTD data transfer at 5.4 MHz.

B. SCAN CONVERSION

After realizing the ability to transfer data into the framegrabber at high speeds, the remaining goal of this project was to remap the bytes of data into a proper format in a frame buffer, expand the ninety line image into 450 lines, and then display the

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data on the video monitor. The method was successful and as of this writing hundreds of frames of IRSTD data have been read into the framegrabber, unscrambled and displayed. Figures 9 and 10 are unscrambled infrared scenes produced in this project using a gray color scale. Figure 9 is a 90-line version and Figure 10 is an expanded 450-line version. Both scenes were photographed from the video monitor with a 35 mm camera. The difference in contrast of the two figures is due to the exposures of the photographs. This difference in contrast is not apparent on the video monitor. Note that the expanded version provides a much more discernable image than the 90-line version.

Close inspection of Figure 10 reveals some characteristics of images produces by the IRSTD. First, midway down the scene there is a band of data that is a lighter shade of gray than the rest of the upper portion of the scene. This is due to DC offsets in ten of the detectors in the lead array. When expanded by a factor of five, the offsets appear as a band of 50 rows in the 450 line image.

Secondly, near the bottom of the scene there is a black band. This band is caused by one detector that was inoperable at the time the data was recorded from the IRSTD. On the 450 line image it shows up as a five line band containing no information.

Lastly, there is some distortion to the scene due to the expansion into 450 lines. This is apparent in the lower half of Figure 10 where scene data appears in bands rather than a smooth, coherent picture. Still, after comparison with Figure 9, the type
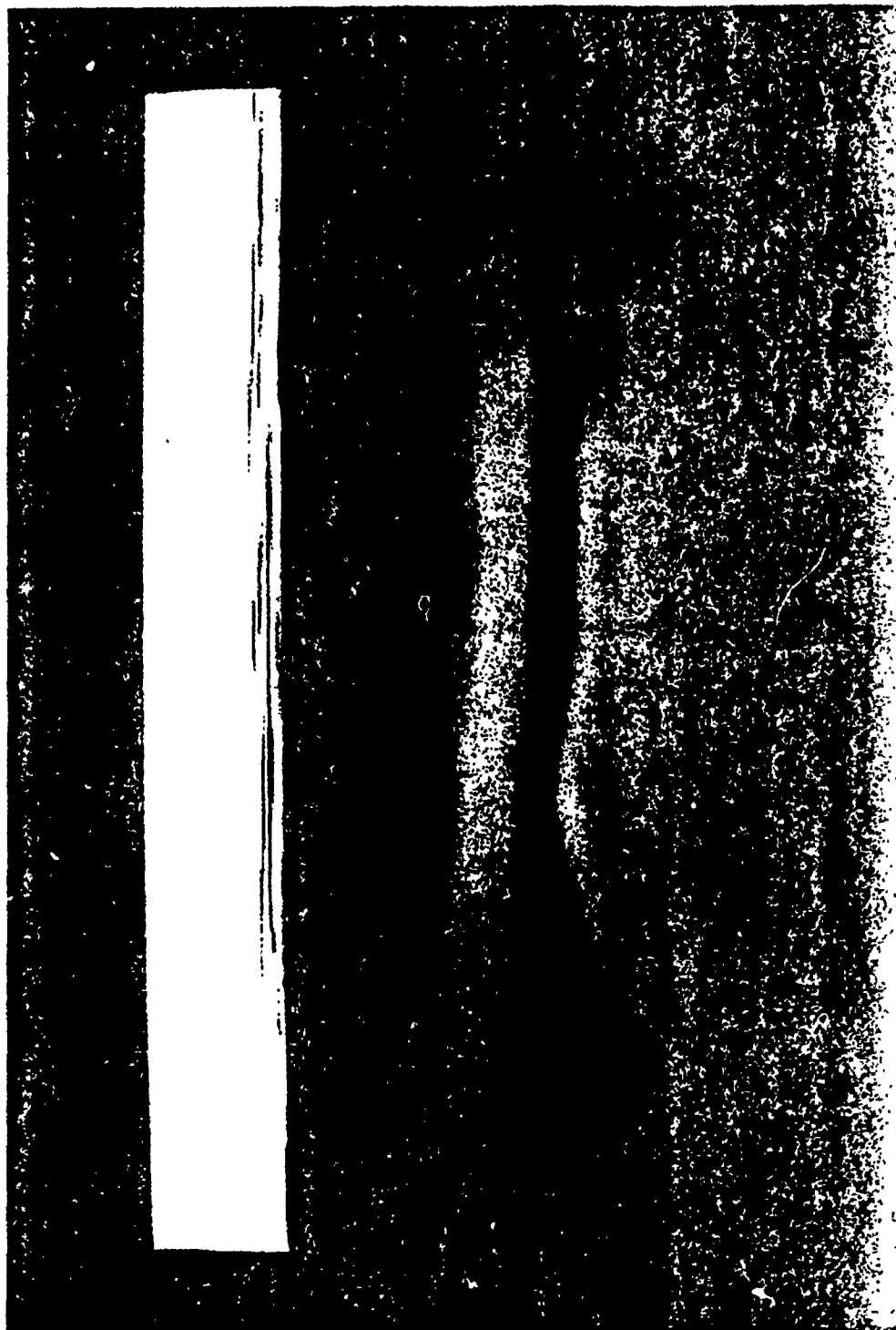
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Figure 9 Photograph of Unscrambled Data in 90 Line Format
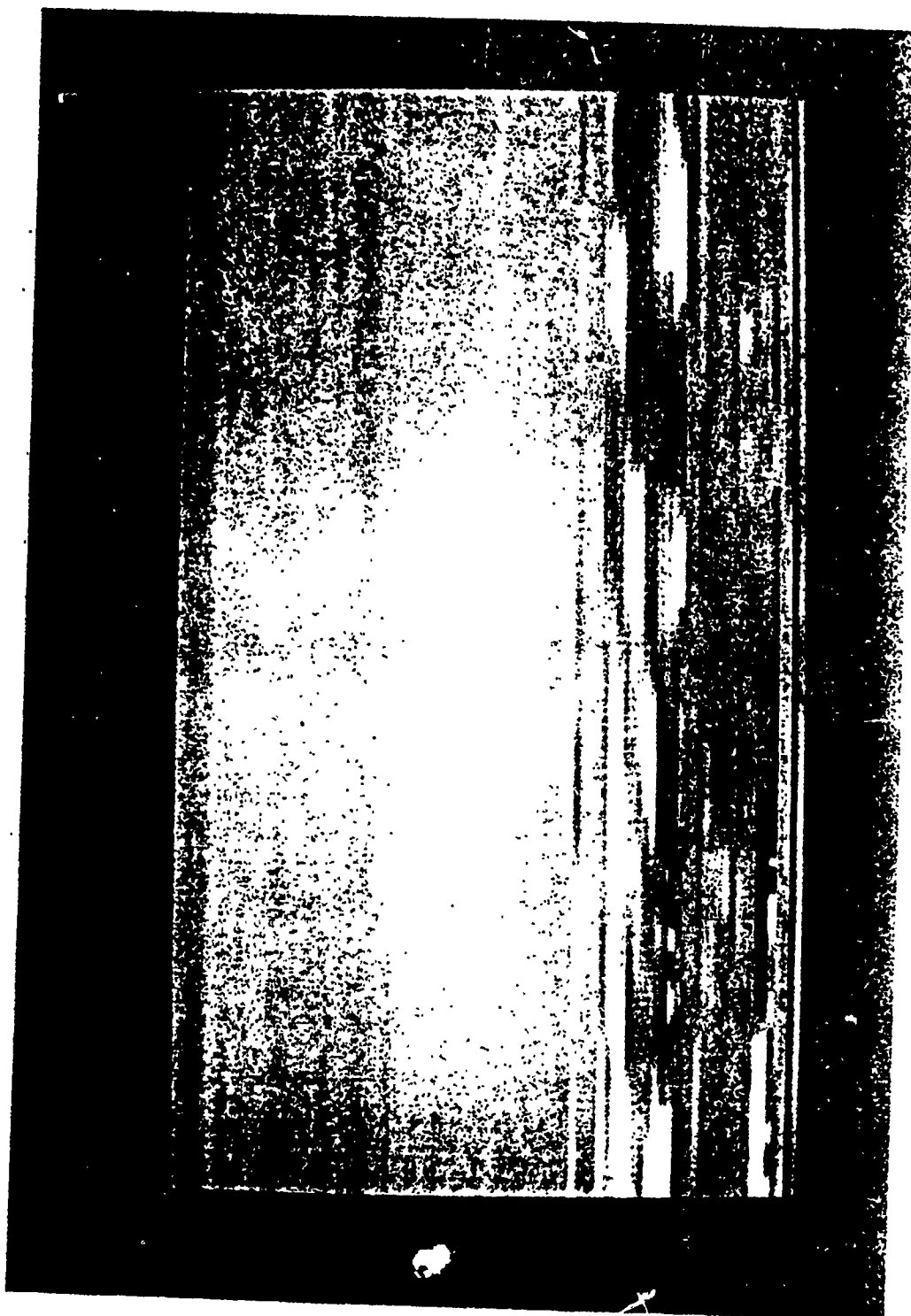
Figure 10   Photograph of Unscrambled Data in 450 Line Format

of image created by the expansion is much more desirable than the 90 line image.

One of the major advantages of framegrabber technology is the ability to display images in false color. As a test on the discernability of images produced in this project, several images were acquired, scan converted, expanded and displayed using a standard false color scale implemented with DT-IRIS commands [Ref. 7]. Figures 11 and 12 are a 90 line version and 450 line version of scene data produced using this false color. Again, the discernability of the 450 line image far exceeds that of the 90 line image. Figure 11 illustrates the potential for using false color to represent infrared scenes. Whereas changes in the byte values were very subtle using the gray color scale, the false color representation shows explicitly where the values of bytes of information and hence the radiance distribution of the scene changes. The DC offsets, barely visible with the gray color scale, are now obvious in false color. In addition, five line bands corresponding to an individual detector scan are also much more apparent in false color.

C. PROCESSING TIME CONSIDERATIONS

The complete data capture, unscramble, enlarge and display sequence takes slightly under four seconds. The purpose of real-time image display of IRST data is to aid the operator in cuing target track declaration and in eliminating false targets. For
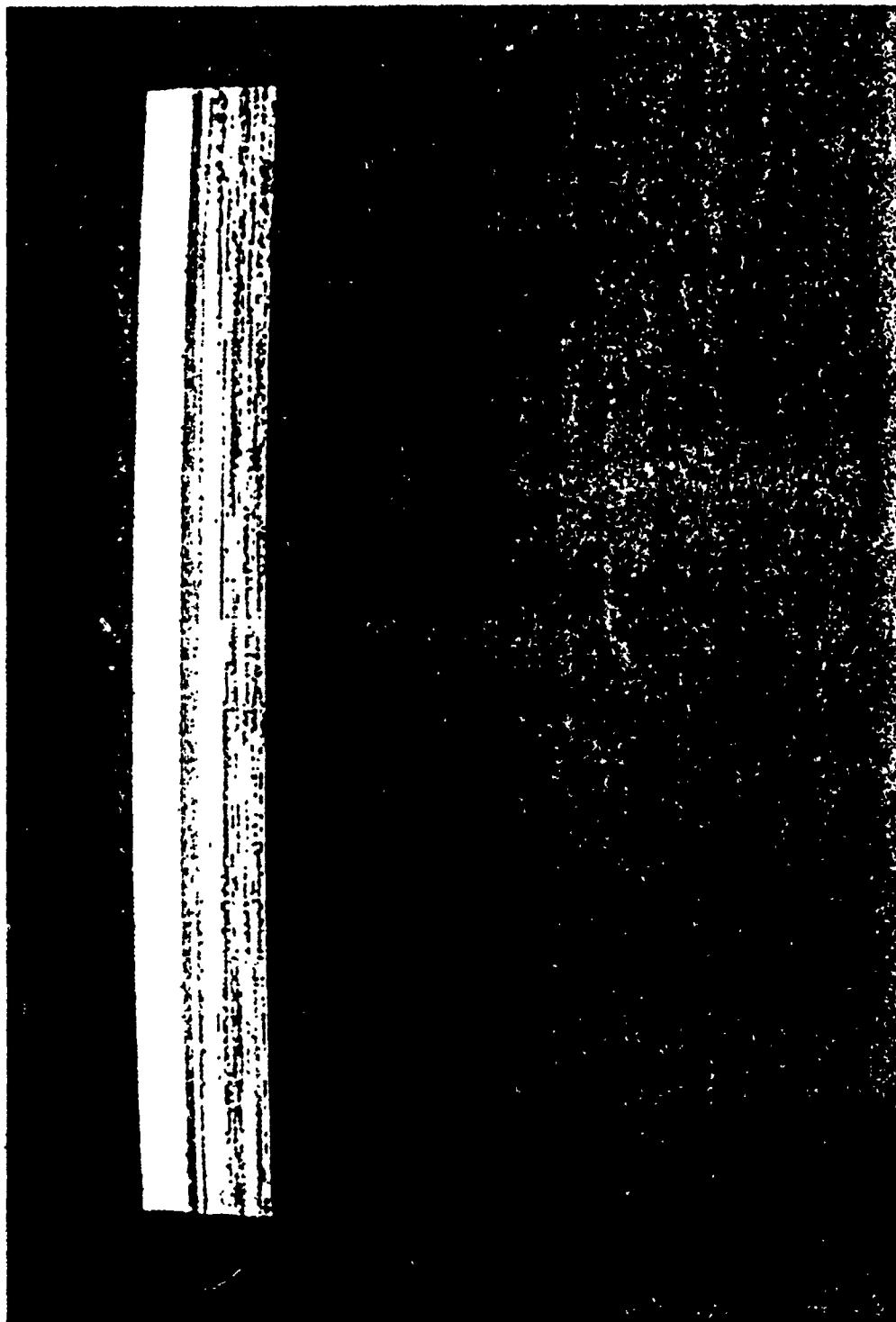
Figure 11 Photograph of Unscrambled Data in 90 Line Format Using
False Color Scale
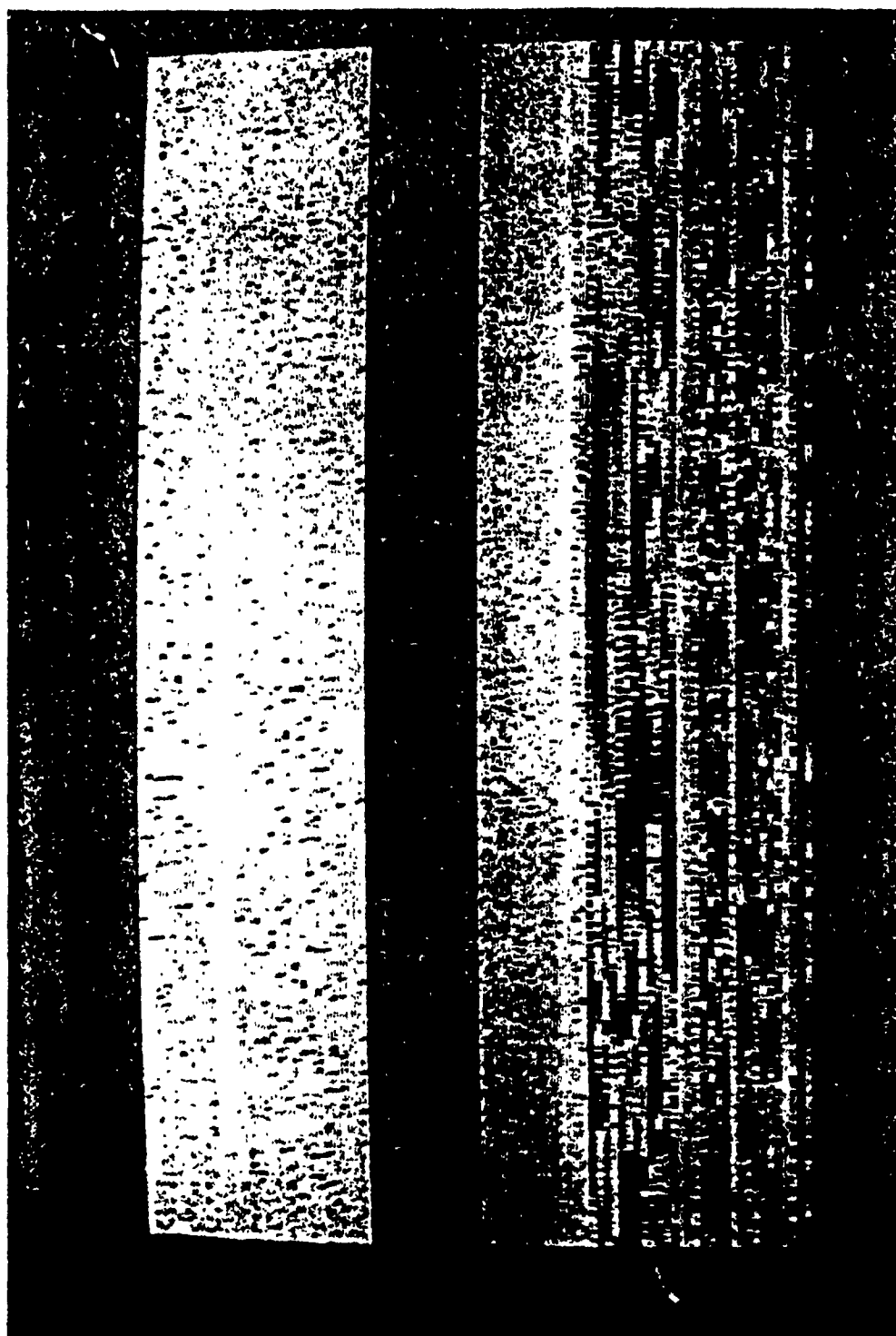
Figure 12   Photograph of Unscrambled Data in 450 Line Format
Using False Color Scale

this purpose, it is required to display each successive scan of the same sector on each rotation of the scanner. For the NPS-IRSTD, this requires completion of the unscrambling and display cycle inside the rotation time of two seconds. Thus, the current processing and display cycle allows a near-real-time display sequence consisting of data obtained every second rotation.

At this point, a discussion of the amount of time consumed by the various operations involved in displaying an image is in order. Figure 13 is a timeline depicting the time consumed by the various operations involved in producing an image.
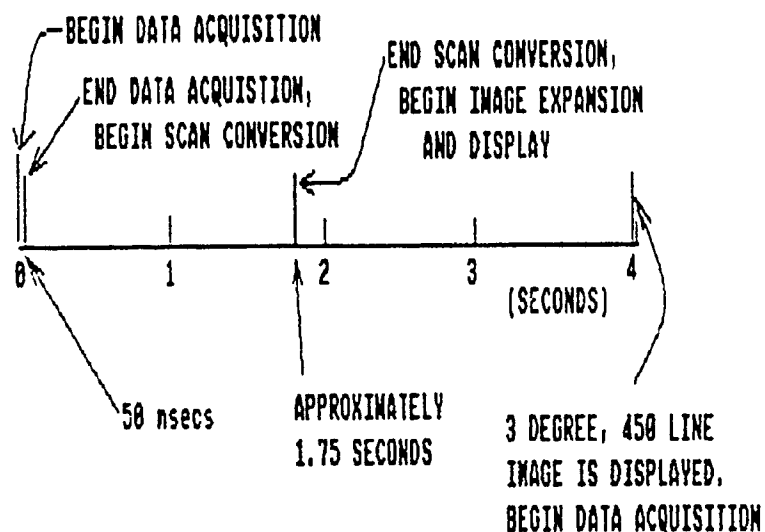
Figure 13 Timeline of Data Acquisition, Scan Conversion and Expansion Process

As shown in Figure 13, the complete process takes approximately four seconds. Loading data into the framegrabber takes only about 50 milliseconds, the scan conversion takes approximately 1.75 seconds, and expanding the 90 line image into 450 lines takes

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nearly 2.25 seconds. Clearly, the display of acquired data within one rotation of the IRSTD scanner requires that the unscrambling and expansion be performed much faster. In scan converting the data, time consumption is due mostly to the requirement of writing the data into an array, manipulating it and then rewriting it to another frame buffer. The restriction of moving only 32767 bytes of data at a time requires eight buffer-to-array-to-buffer transfers of 23040 bytes each. This appears extremely inefficient, but unfortunately it is an uncontrollable factor built into the DT2861 Frame Grabber. Furthermore, the expansion of the image into 450 lines requires 450 subroutine calls, another uncontrollable factor.

While it is possible that the scan conversion and expansion algorithms are not as efficient as possible, it must also be recognized that faster methods of scan conversion and expansion still might not narrow the entire operation down to less than a two second time frame. If much faster algorithms are not possible, then another method besides software manipulation of data must be investigated. One such possibility for improving the cycle time is to perform the unscrambling and expansion using electronic circuitry. Generally, handling of data with Transistor-to-Transistor Logic (TTL) circuits is much faster than with software since the data does not have to be shuffled between memory buffers.

IV. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Following design and construction of the direct data acquisition interface for the DT2861 Frame Grabber, successful acquisition of test data at rates up to 5.4 MHz has been demonstrated. Scene data corresponding to 3° sector images have been acquired, scan converted and expanded both in gray scale and in false color. Acquisition of tape recorded scene data for scan sectors at data rates of 4.32 MHz, limited by the tape recorder play back speed, and scan conversion and display in video format has been demonstrated with a cycle time of less than 4 seconds. Potential for decreasing cycle time exists by improving algorithm and programming efficiency and replacing software with hardwired modules. With these improvements, the current level of display of alternate scan scenes in real time with a four second update time is expected to be raised to display of every scan with a two second update time, which is the limit of the IRSTD scanner.

Although the ability to display images in real time has not been realized, there are nevertheless several positive aspects to the completion of this project. The ability to display scene data within four seconds is a vast improvement over previous techniques. Now available is a relatively inexpensive personal computer based near real time infrared imaging system. There is now potential for evaluating and calibrating the IRSTD in a short time. Furthermore,

used in conjunction with framegrabber image processing capabilities such as subtraction, multiplication and convolution, this system is potentially a valuable educational tool for students studying electro-optics at NPS. Lastly, with improvements in processing time, the use of framegrabber technology for real time display with the IRSTD appears to have a promising future as a shipboard sensor or land-based system used to conduct research in background suppression or target enhancement through filtering techniques.

B. RECOMMENDATIONS

This system has excellent potential future in naval applications, research, and education. There are several improvements that can be implemented, however, both for the short and long term. These improvements are listed below:

- A concentrated effort is required to restore the IRSTD to operating condition since the disruption of cabling and processing hardware in Room 703. It has been reported that a full two weeks of concentrated effort may be required to return to operation.

- A method of allowing the user to view the same sector of data on successive rotations should be researched. Ideally, a user could choose to continuously view the same sector of data or sectors at random, as is now the case.

- Research should be conducted into finding a more efficient method of expanding the 90 line image into 450 lines. Presently 450 subroutine calls involving arrays are used to expand the image. DT-IRIS supports the languages PASCAL and C. Perhaps these languages will provide more a more efficient means manipulating arrays.

- In his thesis project [Ref. 1], Lt. Engel developed many image processing routines, such as changing the lookup color tables and correcting images for detector DC offsets. His programs operate on a particular image format, and either they should be altered to operate on an image using the author's format or

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the author's image format should be altered to be compatible with Engel's image format.

- If it turns out that the unscrambling and expansion software cannot be made more efficient, unscrambling and expanding the digitized data using hardware should be researched. This would eliminate any need to download data from the framegrabber into an array and then reload it into the framegrabber for display. Hardware scan conversion and expansion would likely be a very fast process.

I. COMPUTER PROGRAM LISTINGS

A. LOAD.FOR

```
C
C    PROGRAM LOAD.FOR      WRITTEN BY: LT. MICHAEL J. BACA
C                             LAST REVISION: 18 SEP 90 BY M.J. BACA
C  THIS PROGRAM INITIALIZES AND INSTRUCTS THE DT 2861 FRAME GRABBER
C  TO READ A FRAME OF DATA FROM ITS EXTERNAL PORT.  BY CHANGING
C  THE LINE MARKED "C**" AN EXECUTABLE STATEMENT RATHER THAN A
C  COMMENT LINE, THIS PROGRAM WILL DISPLAY WHAT IS HAS READ INTO
C  BUFFER #1 VIA THE EXTERNAL PORT.
C
C
        CALL ISINIT
        CALL ISDISP(1)
        CALL ISOTFR(4)
        CALL ISINFR(1)
        CALL ISSETR(0,0,512,512)
        CALL ISRDEP
C**     CALL ISOTFR(1)
        CALL ISEND
        END
```

B. UNSCRAMB.FOR

```
C  PROGRAM UNSCRAMB.FOR   WRITTEN BY: LT. MICHAEL J. BACA
C              LATEST REVISION: 18 SEP 90 BY MJBACA
C  THIS PROGRAM WILL UNSCRAMBLE AN IMAGE THAT HAS BEEN PLACED INTO
C  BUFFER 1 OF THE FRAMEGRABBER, EXPAND THE IMAGE BY A FACTOR OF
C  FIVE AND THEN DISPLAY IT ON THE VIDEO MONITOR.  THE FINAL,
C  UNSCRAMBLED IMAGE WILL BE 512 X 450.
C
**************************************************************C
C  THIS SECTION SIMPLY DEFINES ALL THE VARIABLES, AND ARRAYS
C  AND INITIALIZES THE FRAMEGRABBER BOARD.
C
        INTEGER*2 SCRAM(23040', UNSCRAMB(23040), ARRAY(90,128)
        INTEGER*2 IC, ICLR
        INTEGER IX, IY, IROW, ICOL, KA, JA, IA, ISECT
        INTEGER M,L,J,K,IAROW,IBROW,ICROW,IDROW,IEROW
        INTEGER*2 A(512),B(512),C(512),D(512),E(512),TEST(450)
        EQUIVALENCE(A,B,C,D,E)
```

```
      CHARACTER*30 FILE$,ANSWER$
      ICOL  = 0
      KA = 0
      CALL ISINIT
      CALL ISDISP(1)
C
C  THE NEXT LINE IS INSERTED TO MAINTAIN A CONTINUOUS DISPLAY OF
C  THE CONTENTS OF BUFFER FOUR, WHICH IS THE BUFFER THAT THE
C  UNSCRAMBLED, EXPANDED IMAGE WILL BE PLACED IN.
      CALL ISOTFR(4)
C*******************************************************************C
C THIS SECTION UNSCRAMBLES THE DETECTORS, BUT NOT THE DETECTOR
C ARRAYS.
      ICOL = 0
      DO 430 IROW = 0,135,45
      K = 0
      CALL ISGETP(1,IROW,0,23040,SCRAM)
          DO 400 IX = 0,127
            DO 410 L = 180*IX+1, 180*IX+15
              J = L + 165
                DO 420 M = L,J,15
                K = K +1
                UNSCRAMB(M) = SCRAM(K)
 420              CONTINUE
 410          CONTINUE
 400      CONTINUE
      CALL ISPUTP(2,IROW,0,23040,UNSCRAMB)
C  BY INCLUDING THE FOLLOWING LINE, IT IS POSSIBLE TO VIEW THE
C  IMAGE WITH THE DETECTORS UNSCRAMBLED, BUT THE ARRAYS STILL IN
C  A HORIZONTAL POSITION.
C      CALL ISOTFR(2)
C
C
 440      CONTINUE
C
C
C
*******************************************************************C
C THIS SECTION WILL UNSCRAMBLE THE DETECTORS ARRAYS.  THEY ARE
C PRESENTLY IN ORDER HORIZONTALLY, AND MUST BE PLACED VERTICALLY.
C IT IS DESIRED THAT ONLY EVERY OTHER ARRAY, STARTING WITH THE 2ND
C ONE BE DISPLAYED.  THUS, ONLY EVERY OTHER ARRAY IS OPERATED ON.
C NOTE THAT A 90 BY 128 ARRAY IS USED.
C
      KA = 90
       DO 500 IA = 1,128
         DO 510 JA = 1,90
           KA = KA + 1
           ARRAY(JA,IA) = UNSCRAMB(KA)
 510      CONTINUE
         KA = KA + 90
 500    CONTINUE
```

```
C
C
C********************************************************************C
C  THIS SECTION TRANSFERS THE DATA FROM THE 90 BY 128 ARRAY INTO A
C  SIMPLE SINGLE COLUMN ARRAY.   THIS IS NECESSARY BECAUSE THE
C  WINDOWING DT-IRIS
C  SUBROUTINES REQUIRE SUCH ARRAYS.
C
       KA = 0
          DO 610 JA = 1,90
           DO 600 IA = 1,128
              KA = KA + 1
              UNSCRAMB(KA) = ARRAY(JA,IA)
  600      CONTINUE
  610      CONTINUE
          CALL ISSETR(0,ISECT,90,128)
          CALL ISPUTR(3,UNSCRAMB)
C
C
C THE NEXT LINE, IF USED WOULD DISPLAY THE UNSCRAMBLED DATA IN A
C 512 BY 90 FORMAT.
C
C          CALL ISOTFR(3)
C
C
          ISECT = ISECT + 128
  430     CONTINUE
C********************************************************************C
C  THIS SECTION EXPANDS THE DATA FROM 90 LINES TO 450 LINES.
C
          IROW = 0
          DO 800 IROW = 0,89
             CALL ISGETP(3,IROW,0,512,A)
             IAROW = 5*IROW
             CALL ISPUTP(4,IAROW,0,512,A)
             IBROW = 5*IROW + 1
             CALL ISPUTP(4,IBROW,0,512,B)
             ICROW = 5*IROW + 2
             CALL ISPUTP(4,ICROW,0,512,C)
             IDROW = 5*IROW +3
             CALL ISPUTP(4,IDROW,0,512,D)
             IEROW = 5*IROW + 4
             CALL ISPUTP(4,IEROW,0,512,E)
  800     CONTINUE
C   THE NEXT LINE DISPLAYS THE FINAL 512 BY 450 UNSCRAMBLED
C   IMAGE.
          CALL ISOTFR(4)
          CALL ISEND
          END
```

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C. REALTIME.BAT

LOAD
REALTIME

I. INSTRUCTIONS FOR COMPILING AND LINKING FORTRAN PROGRAMS

This appendix is intended to provide future users of the IRSTD computer system with basic instructions for compiling and linking the programs listed in Appendix A. Explicit instructions on compiling and linking may be found in Reference 9.

A. COMPILING AND LINKING

The compiler used in this project was the Microsoft FORTRAN 4.1 Optimizing Compiler. This compiler uses ANSI 77 FORTRAN. I found that compiling and linking was easily completed in a few simple steps. The first step is, of course, to use some type of editor to write a FORTRAN program. Any editor will suffice, but as a matter of convenience I chose the Microsoft Editor. To enter the editor you must first be in the BIN subdirectory in the D drive of the NIC PC. At the prompt type "m <program name>.for", then press ENTER. This will get you into the program and allow you to edit it. To get out of the editor press the F8 key. Your program will automatically be saved with the .for extension.

The next step is to compile the program. At the DOS prompt (still in the BIN subdirectory), type "fl <filename>.for", then press ENTER. You **must** include the .for extension. Your program will begin compiling and will automatically link with the FORTRAN subroutine library LIBFOR7.LIB. Soon you will see an UNRESOLVED EXTERNAL error message appear on the screen along with several DT-

IRIS subroutines that are unresolved external subroutine calls. Do not be alarmed - this just means that you have not linked with the DT-IRIS subroutine library ISFORLIB.LIB. At the DOS prompt type "link", then press ENTER. You will then be queried for an object file. This is a file that was created when you compiled the program. Type in the name of the object file. It will have the same name as your program, except it will have a .obj extension instead of a .for extension. It is not necessary to type the .obj extension when queried for the object file. You will then be queried for a RUN file and a LIST file. Just press ENTER at both of these queries. Next, you will be queried for a library. Type "ISFORLIB.LIB", then press ENTER. The computer will make a few noises and in a few seconds you'll get the DOS prompt again. If you have done everything correctly, you will have a <filename>.exe file in the BIN subdirectory. To run your program simply type in <filename> at the DOS prompt.

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